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Paraspinal Muscle Function Assessed with the Flexion-Relaxation Ratio at Baseline in a Population of Patients with Back-Related Leg Pain

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Abstract

Objective: The purpose of this study was to assess back muscle status at baseline in patients with back-related leg pain (BRLP) and to correlate those findings with baseline demographic and clinical factors.
Methods: Surface electromyography (EMG) and electromagnetic motion-tracking detected flexion-relaxation response in 135 patients with BRLP. Surface EMG electrodes were attached with standard skin preparation over the right and left paraspinal muscles at L3. Participants moved from upright standing into full forward flexion, rested flexed for 1 second, and returned to the upright position. A flexion-relaxation ratio (FRR) factor was calculated as the root mean square EMG amplitude during forward flexion divided by the activity at full flexion.
Results: High repeatability was found (intraclass correlation coefficient $[ICC]_{[1,3]} = 0.94$ and 0.86) between 3 cycles of assessment at the same session. Patients with BRLP exhibited low FRR values, indicating a loss of the flexion-relaxation response similar to that seen in low back pain patients. Patients with very low FRR had higher Roland-Morris Disability Questionnaire scores than the other patients, had increased incidence of straight leg raise test, and had decreased range and rate of forward flexion.
Conclusions: A subgroup of patients with BRLP was identified with very low FRR who exhibited more disability and clinical findings and decreased motion. The use of the inverted FRR factor, expressing muscle activity at the fully flexed and resting position as a percentage of peak activity during flexion, provides more stable numerical behavior and another perspective on interpreting FRRs. (J Manipulative Physiol Ther 2011;34:594-601)
Key Indexing Terms: *Low Back Pain; Spine; Biomechanics; Electromyography; Chiropractic*

Despite a wealth of research on the topic, low back pain (LBP) remains a significant individual and societal burden in developed countries. Lifetime prevalence has been estimated to be 80%,[1,2] with health care costs in the United States on the order of $100 billion dollars annually.[3] Back-related leg pain (BRLP), in which painful symptoms extend into the hip, buttocks, thighs, and legs,[4,5] is a common variation of LBP.[6-8] Lifetime prevalence estimates are as high as 40%.[7] Back-related leg pain is often more disabling than LBP and accounts for greater work loss, recurrences, and costs than uncomplicated LBP.[9-12] Back-related leg pain more often results in the need for surgery, including surgery to repair vertebral disc herniation.[12,13]

Back-related leg pain of radicular origin is associated with lumbar nerve root irritation, often due to herniated lumbar disks[14-16] or spinal stenosis, nerve root canal narrowing, and synovial cysts.[17] Inflammation may also be caused by biochemical mechanisms.[18] Back-related leg pain may also be of nonradicular origin, thought to be caused by biomechanical dysfunction or pathological changes in the paraspinal muscles, ligaments, disks, facet joints, or other structures of the lumbar motion segments.[19]

A multisite, randomized, clinical trial was performed that compared chiropractic care and self-care for patients with BRLP.[20] The primary outcome measures in that

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clinical trial were patient self-reported pain and dysfunction. In addition to clinical outcomes assessed in the trial, the study involved a set of secondary outcomes designed to evaluate spinal function. These secondary outcomes provide more information about the etiology of BRLP by measuring regional motion, postural control, muscle endurance, and dynamic muscle function. The present study specifically addresses the methods used to assess the muscle function using the flexion-relaxation (F/R) test and describe the baseline findings in relation to baseline clinical variables.

The F/R phenomenon has been used for many years as a way to test the reaction of the paraspinal muscles to the loading imposed by forward trunk flexion. In pain-free participants, the paraspinal muscles are observed to become electrically silent (ie, relaxed) with full forward flexion. Back pain and disability have been associated with a loss of this electrically silent period.[21,22] In addition, recent studies suggest that the phenomenon can be modulated with treatment.[23-25] The objectives of this study were to assess the F/R phenomenon in patients with BRLP, a subgroup of patients with LBP who also suffer with radiating leg pain. We sought to compare the F/R responses to other populations reported in the literature and also investigate relationships between F/R responses and demographic and clinical factors exhibited in our patient sample.

Methods

We recruited patients for the study using primarily direct-mail marketing efforts over a 3-year period in 2 metropolitan areas in the midwest. All assessments and treatments took place in the research clinics of the 2 chiropractic colleges located in those midwest towns. This study and all procedures and consent forms were approved by the institutional review boards of Northwestern Health Sciences University and Palmer College of Chiropractic. The inclusion and exclusion criteria, details of the screening process, and methods for collecting patient self-report measures are described fully in the study protocol paper by Schulz et al.[20] In brief, patients were included if they had subacute or chronic BRLP of at least 4 weeks of duration. Back-related leg pain included radiating pain into the proximal or distal part of the lower extremity, with or without neurological signs, with possible nerve root compression. Patients were 21 years old or older and must have reported leg pain at a level of 3 or above on a 10-point scale. Initial screening was performed by telephone interview. Eligible participants were scheduled for a baseline visit to review and sign consent forms, fill out baseline questionnaires, and be screened by study physicians.

At the second baseline visit and before randomization to treatment group, all participants in the study underwent a biomechanical testing session. Objective testing was performed by examiners trained and certified in testing

Fig 1. *Locations and fixation methods for the electrodes and sensors used. Electromyography electrodes are placed bilaterally over the muscle bellies at the level of L3. (Note: it is difficult to see the electrode on the left because of the lighting and the low contrast between the tape over the electrode and the skin.) Polhemus motion tracking sensors are attached to stiff plastic plates and held closely to the body with elastic straps at the T12 to L1 level and at S2.*

protocols. The testing laboratories at both sites had identical equipment including an electromagnetic sensor system for tracking motion (Polhemus "Liberty"; Colchester, VT), a force plate for measuring ground reaction forces and moments (Model no. 4060-NC Forceplate; Bertec, Inc, Columbus, OH), a 4-channel electromyography (EMG) amplifier (Delsys, Inc, Scottsdale, AZ), and custom load cells and accelerometers. All sensor systems were interfaced to an A/D converter with recordings performed using Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL).

Lumbar Paraspinal Muscle F/R

The methodology for the F/R test was based on the work of Watson et al.[26] The protocol improved on past methods by incorporating noncontact trunk motion measurements, surface EMG recordings, and ground reaction forces, all recorded simultaneously.

The recording sensor placement and setup is shown in Figure 1. For EMG, double bar–style EMG electrodes were placed over the right and left paraspinal muscles at the level of L3 and held in place with elastic tape. The thickest part of the muscle was identified by palpation, and the sensors were oriented so that the electrode bars were perpendicular to the muscle fibers. L3 was identified by using the posterior superior iliac spines to locate the L4 to L5 spinous interspace and counting up to the L3 spinous process. The skin underlying the electrode was abraded with an alcohol pad to provide better conductivity, but electrode paste was only used in cases where extreme skin thickness or sweat made contact difficult. The reference electrode was taped over the underside of the left wrist.

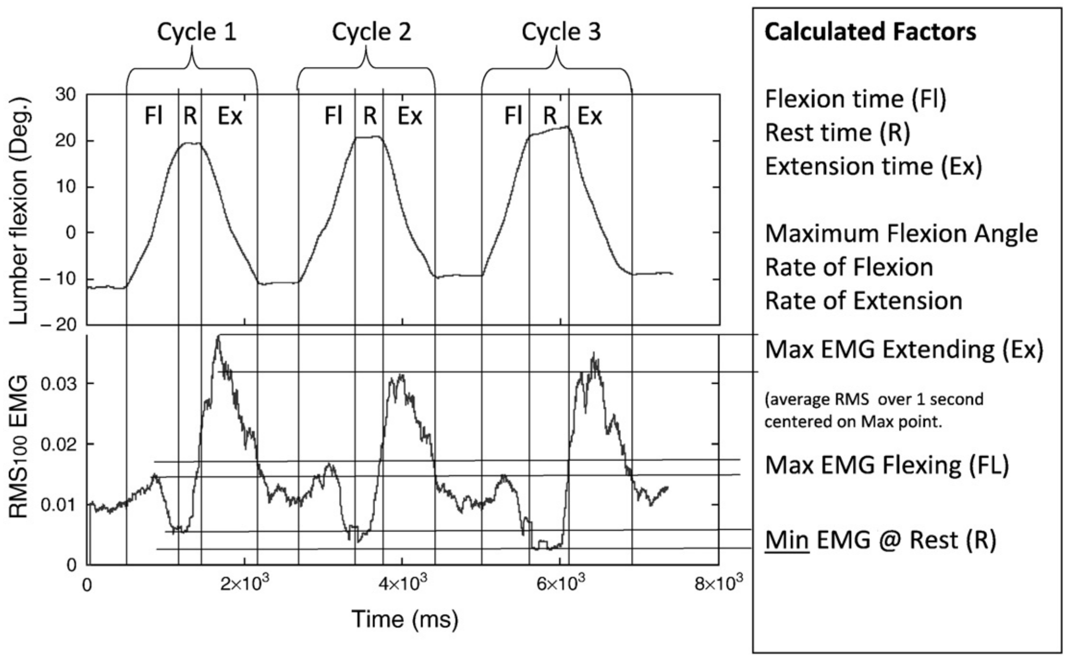

Fig 2. *The data reduction scheme showing the division of lumbar flexion and RMS EMG into epochs based on changes in lumbar flexion angle. The change from upright standing to forward flexion is the beginning of the flexion epoch. The upper plateau indicates the 1-second period of rest at full flexion. Electromyography factors are calculated as 1-second average RMS EMG around the maximum EMG levels detected during flexion and extension and at the minimum level detected during the rest time.*

Spinal motion was recorded using 2 Polhemus sensors attached to stiff plastic plates and held firmly to the spine at the levels of S2 and T12 to L1 with elastic bands going around the trunk. Participants were instructed to move from an upright standing posture into full forward flexion in a smooth manner over 6 seconds. Full flexion was maintained for 1 second, followed by a return to the upright position over another 6 seconds. After a 3-second rest, the movement was repeated. The examiner counted the time out loud and provided cues to guide the motion. The participant was allowed to practice the motion until the proper cadence was performed consistently. A total of 3 cycles of EMG and position were recorded.

Data Reduction

Electromyography and position data were processed using Mathcad software (version 12; Parametric Technology Corporation, Needham, MA) and custom routines. Automated routines in Mathcad scanned the position channel data and located the times of the onset of flexion, the point of full flexion, the onset of extension, and the return to the upright position for each cycle of motion. The software operator was able to correct the locations manually if the algorithm did not find the points accurately. Using these time points, the software calculated the lumbar flexion angle, the rates of flexion and extension, and the amount of time in seconds for the fully flexed position (Fig 2).

The EMG signal was rectified, and the root mean square (RMS) was calculated with a 100-millisecond window to produce continuous traces of left and right activity with respect to time. The EMG signal was divided into epochs based on the time points identified in the position data channel. The epochs are identified in Figure 2 as the flexion, rest, and extension times.

Electromyography factors were then calculated from the signals within those epochs. For instance, the maximum flexing EMG activity was the average RMS EMG for the 1-second period around the maximum EMG signal that occurred during the flexion phase. This factor showed the level of activity when the muscles were eccentrically contracted during the slow, controlled, forward flexion task. The extent to which the muscles became electrically silent during full forward flexion, on the other hand, was assessed as the average RMS EMG for the 1-second period around the minimum EMG signal during the fully flexed "resting" epoch.

Electromyography measures are subject to differences in amplification, sampling rate, and electrode contact that are difficult to account for when comparing measures across time or across individuals. Following the example of Watson et al,[26] we calculated a F/R ratio (FRR) as the maximum EMG during forward flexion divided by the minimum resting (fully flexed) EMG. Expressing EMG factors as ratios has the advantage of providing a normalized EMG factor, which makes it possible to compare EMG factors over time and across individuals.

Table 1. *Demographic, clinical, and calculated F/R factors in patients with BRLP at baseline*

Factor	Minimum	Maximum	Mean	SD
LBP numeric rating (0, no pain; 10, worst)	0.0	10.0	5.36	2.22
Leg pain numeric rating (0, no pain; 10, worst)	3.0	9.5	5.48	1.67
RMDQ (0-23)	1	23	10.32	5.07
Fear avoidance beliefs—work (0-30)	0	30	9.79	7.94
Fear avoidance beliefs—physical activity (0-30)	0	23	10.68	5.26
SLR, LT side pos (°), n = 38	33	92	66.2	12.6
SLR, LT side neg (°), n = 97	43	97	75.2	11.9
SLR, RT side pos (°), n = 43	28	89	66.9	14.6
SLR, RT side neg (°), n = 92	37	110	77.6	13.0
Height (in)	59	76	66.25	3.44
Weight (lb)	121	280	173.68	33.79
BMI (kg/m^2)	19.31	45.34	27.79	4.86
Age (y)	27	92	57.20	12.04
Average RMS EMG standing, LT side	0.0021	0.0520	0.0089	0.00687
Average RMS EMG standing, RT side	0.0021	0.0303	0.0084	0.00542
Average RMS EMG during flexion, LT side	0.0038	0.1107	0.0155	0.01149
Average RMS EMG during flexion, RT side	0.0036	0.0523	0.0150	0.00902
Average RMS EMG at full flexion (rest), LT side	0.0020	0.0340	0.0084	0.00621
Average RMS EMG at full flexion (rest), RT side	0.0018	0.0510	0.0087	0.00755
Average RMS EMG during extension, LT side	0.0083	0.1617	0.0291	0.01842
Average RMS EMG during extension, RT side	0.0052	0.0857	0.0270	0.01432
F/R ratio, LT side	0.89	36.31	2.70	3.30
F/R ratio, RT side	0.87	9.62	2.58	1.98
Maximum vertical force (N)	22.92	1413.00	785.78	171.66
Maximum lumbar flexion (°)	15.86	67.08	41.23	11.39
Rate of extension (°/s)	−10.56	0.64	−3.20	2.56
Rate of flexion (°/s)	1.41	27.84	10.92	5.84
Time spent fully flexed (at rest) (s)	0.77	5.36	2.52	0.85

N = 135. Electromyography factors in mV. *LT*, left; *RT*, right; *pos*, positive; *neg*, negative.

Although FRR is a commonly reported factor used in the literature, we also calculated an inverse FRR (1/FRR) as a second ratio factor. The 1/FRR has the added advantage of being bounded in a way that permits interpretation from another perspective, with the minimum RMS EMG value in the numerator. This avoids potential division by an RMS EMG value approaching 0 and decreases variance; thus, providing better numerical behavior. Inverse FRR is essentially the percentage to which the lumbar muscles become electrically silent during full flexion in comparison with the higher activity seen during forward flexion. Values typically range between 0 and 1 because the fully flexed (resting) EMG levels rarely exceed the EMG activity during flexion. When 1/FRR is 0, it indicates that full electrical silence in the minimum RMS EMG value was achieved; 1 would represent no silence at all in the minimum RMS EMG value.

Data Analysis

Data reduction produced 60 variables, including motion variables, left and right EMG variables, and ground reaction forces. We merged these variables and the clinical and demographic variables from patient self-report questionnaires[20] into a single database for analysis using SPSS (version 17; SPSS, IBM Company, Chicago, IL). We assessed the reliability of the measures by comparing between cycles on the same patient at the same session. We then performed an exploratory descriptive analysis to identify relationships between EMG factors and motion variables. Finally, we divided the data set into 2 subgroups based on FRR value and tested for differences in clinical and demographic variables between those subgroups.

Results

Over the course of the trial, 192 participants were recruited for the clinical trial. Of those, 135 participants provided complete data sets for the F/R test at baseline. Electrical noise in the remainder of the recordings made data reduction problematic, and those records were omitted from the analysis. Table 1 shows descriptive statistics for a selection of demographic and clinical factors as well as the F/R factors derived from data reduction from these 135 participants.

In general, the patients reported moderate to severe low back and leg pain (mean values, 5.4/10). Disability scores were also moderate to severe (10.3/23). Fear avoidance beliefs (FABQ) scores were in the mild-to-moderate range (FABQ work, 9.8/30; FABQ activity, 10.7/30). Approximately 1/2 of the patients exhibited positive signs on the straight leg raise (SLR) test (38/135

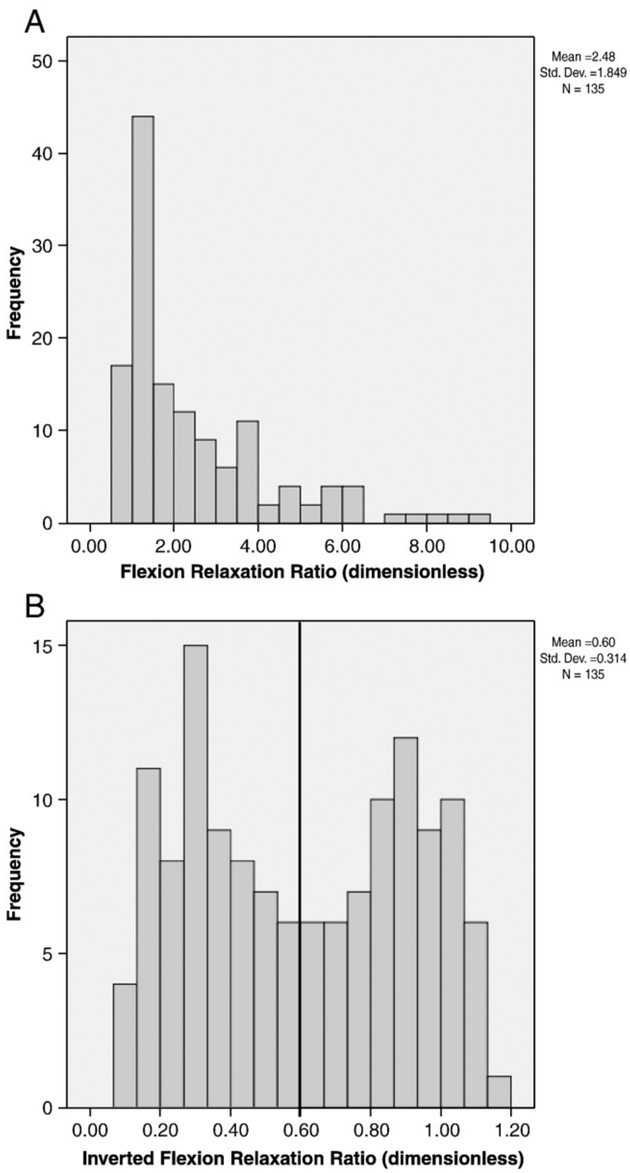

Fig 3. *Frequency distributions of (A) the FRR (FRR = maximum flexing EMG/minimum rest EMG) and (B) the 1/FRR. Note the bimodal distribution of 1/FRR with a splitting point at 1/FRR, 0.6.*

on the left, 43/135 on the right), including pain in the affected limb and reduction in leg raising angle. The mean age was 57.2 years, and body mass index (BMI) was in the high range (mean, 27.8 kg/m^2).

Our analysis of the repeatability of the calculated FRR factors between cycles showed very high repeatability, with $ICC_{(1,3)}$ = 0.94 for the left side and 0.86 for the right. Based on this analysis, we calculated the mean values of the 3 cycles for each factor and used those in further analysis. The EMG and FRR factors shown in Table 1 are mean values of the 3 cycles.

An inspection of the distribution histogram for the FRR variable showed it to be quite skewed, but the inverse of the FRR (with the generally higher EMG value during flexion in the denominator) is quite well bounded (Fig 3). A histogram of the 1/FRR showed an interesting bimodal character that suggested a cut point (1/FRR, 0.6) for dividing the data set into high and low FRR cases.

Significant differences appear in the high vs low FRR subgroups (Table 2) with respect to several demographic and clinical variables. The mean FRR in the high group was 4.0 vs 1.3 in the low FRR group. Patients in the low FRR group tended to be heavier (183 vs 165 lb) and have greater BMI (29 vs 26.6 kg/m^2). Although pain scores do not differ with the level of FRR, there is a tendency for patients in the low FRR group to have greater Roland-Morris Disability Questionnaire (RMDQ) scores (11.7 vs 9.0). There were no statistically significant differences in FABQ scores between the 2 subgroups. There was a tendency for FABQ scores to be 1 point higher in the low FRR group, but the variances between patients were large.

The manner in which the test is performed also differs somewhat between high and low FRR responders. Low FRR responders do not flex as far, move more slowly during flexion, and spend less time in the fully flexed position.

The results of the SLR test are also related to FRR. In our sample, patients who exhibited a positive SLR, indicating an aggravation of distal symptoms during hip flexion, were more likely to have very low FRR responses.

Discussion

Our analysis of the baseline data suggests links between an objective measure of muscle function and participant self-report status, demographics, and clinical measures. Overall, the FRR exhibited by this sample of patients with BRLP falls within the bounds of what has been considered abnormal by other authors. Our mean FRR of 2.7 is similar to that found by Watson et al[26] in a sample of chronic back pain patients. They found a mean FRR on the order of 3.0, in contrast to scores of pain-free controls in the range of 12 to 15. In addition, we identified a subgroup of patients who display much lower FRR on the order of 1.2 to 1.3 and have different clinical and demographic values as well, including RMDQ indicating more severe disability. Interestingly, pain levels were not different between our 2 subgroups. There is no clear cutoff value in the literature for judging whether the results of an F/R test are positive or negative. Comparison between studies has been difficult because different factors are used to assess F/R. In general, either integrated or RMS EMG at the fully flexed position or an FRR has been used.[24] Ratios are perhaps better in that they allow for comparison between subjects because the ratio is normalized to take into account variations in skin-electrode conduction and signal processing. Our semiautomated method worked well to handle the large amount of EMG

Table 2. *Analysis of differences in factors between high and low responders with respect to FRR*

	High FRR responses (n = 70) Mean (95% CI)	Low FRR responses (n = 65) Mean (95% CI)	Mean difference	SE difference	t_{133}	*P* (2 tailed)
F/R ratio, LT side	4.0 (3.0-5.0)	1.3 (1.2-1.4)	−2.75	0.52	−5.31	.000
F/R ratio, RT side	3.9 (3.4-4.3)	1.2 (1.1-1.3)	−2.66	0.25	−10.49	.000
Leg pain numeric rating	5.4 (5.0-5.8)	5.6 (5.2-6.0)	0.26	0.29	0.90	.372
LBP numeric rating	5.1 (4.5-5.6)	5.7 (5.1-6.2)	0.61	0.38	1.61	.110
RMDQ	9.1 (7.9-10.2)	11.7 (10.4-12.9)	2.63	0.85	3.10	.002
Fear avoidance beliefs—work	9.0 (7.2-10.8)	10.6 (8.5-12.7)	1.56	1.37	1.145	.254
Fear avoidance beliefs—physical activity	10.3 (9.1-11.5)	11.1 (9.7-12.4)	0.73	0.91	0.805	.421
Weight (lb)	164.9 (157.9-172.0)	183.1 (174.3-191.9)	18.18	5.63	3.23	.002
BMI (kg/m^2)	26.7 (25.7-27.6)	29.0 (27.7-30.3)	2.34	0.81	2.88	.005
Maximum lumbar flexion	45.6 (43.3-48.0)	36.5 (33.8-39.2)	−9.18	1.80	−5.10	.000
Time spent fully flexed	2.76 (2.56-2.99)	2.25 (2.08-2.42)	−0.53	0.14	−3.78	.000
Rate of flexion	14.3 (13.2-15.5)	7.2 (6.1-8.4)	−7.13	0.80	−8.93	.000

	Percent positive	Percent positive	χ^2	*P* (2 tailed)
SLR, LT side	20.0	36.9	4.773	.029
SLR, RT side	24.3	40.0	3.834	.050

See Table 1 for units of measure. *LT*, left; *RT*, right.

data associated with the clinical trial. In terms of the calculation of FRR, our method is most similar to those of Watson et al,[26] Geisser et al,[27] and Lalanne et al.[23]

The loss of the F/R phenomenon has been shown to be associated with low back disability scores in previous studies.[21] Our study further showed that even within a population of patients with BRLP, higher RMDQ scores are associated with lower FRR. We also found that FRR is related to lumbar range of motion as well as how the test is performed (ie, rate of flexion and time spent fully flexed). Sarti et al[28] found that the speed of test performance affects F/R but that external loads did not. It is interesting that heavier patients in our trial (ie, with greater loads) tended to display lower FRR.

Taken together, our findings relating back muscle behavior to range of motion, disability, and clinical findings support a muscular control theory of the etiology of back pain and BRLP. Patients with back pain may very well have a sense of disability and instability, born out by the elevated RMDQ scores in the low FRR subgroup. Although FABQ scores were not significantly different in our 2 subgroups, the patients did have restricted movement and tended to move more slowly. Together, these findings paint a picture of people who are tentative in their movements, do not allow their muscles to fully relax during forward flexion and who are aware of a restriction in forward motion. Geisser et al[27] reported similar findings in a population of patients with back pain. They showed a relationship between fear of movement, using the Tampa Kinesiophobia scale, and loss of flexion relaxation. A loss of F/R also might contribute to conversion of back pain from acute to chronic. When muscles cannot relax normally, they will fatigue more quickly, leading to co-contraction of other trunk muscles to help maintain spinal stability.[29]

Radiating leg symptoms found in BRLP add another dimension to decreased forward flexion and increased muscle activity. Many of the participants in the study showed reduced hip flexion during the SLR test. Hip and leg flexions aggravate pain radiation in these patients. During forward flexion, the spine normally flexes first, followed by hip flexion as the person continues to bend forward. Patients with a positive SLR test would tend to be hesitant about flexing in the later stages of the F/R test perhaps either reflexively or purposefully, keeping their paraspinal (and perhaps posterior thigh muscles) contracted to prevent pain. We did not specifically record EMG from the posterior thigh muscles, so we cannot say whether there was higher than normal muscle activity during flexion. We also only monitored lumbar spine flexion angle and did not analyze the hip rotation component of the motion. Future studies should address changes that might occur in FRR because of care given in the clinical trial. Other biomechanical factors in relation to FRR as well as the relationship to changes in patients' clinical findings after care should be investigated.

Limitations

A limitation occurred in the collection of EMG data in the study. Although 192 participants were recruited, electrical noise in the EMG prevented analysis of nearly 60 of those participants' files. We believe that the problem was due to loss of contact of the EMG electrode with the skin during part of the test. We chose the Delsys bar style electrode because the electrodes have an encased preamplifier in the electrode case and, so, have very good signal-to-noise characteristics. Noise is a problem especially during dynamic tests and in the presence of the Polhemus tracking system, which creates an electromagnetic field of its own. Furthermore, the electrodes are reusable and hence more economical. However, the fixed distance between the electrode contact bars may have caused them to briefly lose contact in some cases when the skin stretched in the extreme movement during forward flexion. We only analyzed data when there were 3 complete cycles of flexion during the test. We could recover more data if we were willing to relax that criterion and use recordings even when only 1 good cycle was found on analysis.

Conclusion

Patients with BRLP show loss of F/R similarly to patients with LBP. Flexion-relaxation ratio in these patients is associated with self-rated disability measured with the RMDQ and with the presence of positive findings on the SLR test. Patients with very low FRR tend to show greater disability and decreases in range and speed of forward flexion. The use of the 1/FRR factor, expressing muscle activity at the fully flexed and resting position as a percentage of peak activity during flexion, provides more stable numerical behavior and another perspective on interpreting FRRs.

Practical Applications

- Our protocol for assessing flexion-relaxation produced reliable results at least within the same session.
- Patients with BRLP had similar FRR to patients with back pain, well below the reference range.
- Even within a population of patients with BRLP, higher RMDQ scores are related to lower FRR.
- Flexion-relaxation ratio is related to the SLR in that patients with positive SLR showed less quieting of the paraspinal muscle during forward flexion while standing.
- Flexion-relaxation ratio is related to lumbar range of motion as well as how the test is performed (ie, rate of flexion and time spent fully flexed).
- We recommend use of the 1/FRR factor, expressing muscle activity at the fully flexed and resting position as a percentage of peak activity during flexion.

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